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Fire and land management planning and implementation across multiple scales

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Abstract. Ecosystem conditions on Federal public lands have changed, particularly within the last 30 years. Wildfires in the west have increased to levels close to or above those estimated for historical conditions, despite increasing efforts and expertise in fire prevention and suppression capability. To reverse these trends, planning for fire and land management policies, budgets, and restoration must address multiple decision levels (national, regional, local, and project) and incorporate an improved understanding of conditions and their linkage across these scales. Three fundamental issues are identified and discussed that relate to traditional types of planning and the associated lack of achievement of multi-scale integrated resource and fire objectives. Various examples of planning that address these three fundamental issues at different scales are compared to traditional types of planning. Outcomes predicted for an example national scale landscape dynamics model are used to illustrate the differences between three different multi-scale management scenarios.

Keywords: ecosystem management, landscape ecology, land management planning; fire management planning.

Introduction

To achieve objectives in policy, budget, and restoration planning for fire and land management on Federal public lands at multiple decision levels (national, regional, local, and project), managers need a better understanding of conditions and their linkage across these scales. Planning literature from military to business to engineering applications stresses the importance of strategic planning integrated across the range of important scales and issues (Dieter 1991; Goodstein *et al.* 1992; Miller and Dess 1996; Khalilzad *et al.* 1997). However, natural resource and fire planning for management of Federal public lands, and also for State and private lands, has developed differently and emphasizes independent planning (Allen and Hoekstra 1992; MacKenzie 1997; Hann *et al.* 1998; Haynes *et al.* 1998; Quigley *et al.* 1998; Rieman *et al.* 2000). During the 1990s, to aid integration between fire and resource programs, between agencies, and across scales, many land management agencies adopted an ecosystem management approach focusing on the principles of landscape ecology (Forman 1995; Christensen *et al.* 1996; Grumbine 1997; Haynes *et al.* 1998). Many projects now provide excellent examples of successful integration of natural resource and fire planning using principles of ecosystem management and landscape ecology.

In this paper we (the authors) review the central concepts of multi-scale fire and land management planning as they relate to Federal public land management, and provide examples. In addition, using our analysis of National Forests and Grasslands across the lower 48 States as an example, we discuss integrated, multi-scale land management planning, and propose that such planning may be a useful and cost-effective approach to the complex present-day issues surrounding fire and land management.

The ecological and natural resource literature of the 1990s indicates substantial changes in ecological and social conditions on public lands compared with their 'natural' or pre-Euro-American settlement condition (Delcourt and Delcourt 1991; Brown *et al.* 1994; Brown and Bradshaw 1994; Covington *et al.* 1994; Huff *et al.* 1995; McKenzie *et al.* 1996; Saab and Rich 1997; Agee 1998; Frost 1998; Hann

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et al. 1998; Lee *et al.* 1998; Leenhouts 1998; Raphael *et al.* 1998; Rockwell 1998; Hessburg *et al.* 1999*a*; Landres *et al.* 1999; Swetnam *et al.* 1999; Wisdom *et al.* 2000). Effective fire suppression efforts began in earnest following the large fire season of 1910. During the period between 1910 and up to the 1950s, cumulative area burned by wildfire in the western U.S. decreased. Despite increased fire suppression efforts and improved technology since the 1950s, wildfire has steadily returned to levels comparable to or higher than those encountered at the beginning of the last century (Agee 1993). Particulate levels from wildland fire smoke have followed a similar trend (Leenhouts 1998). Particulates from fossil fuel consumption and road and agricultural dust have increased from pre-settlement levels. Other conditions important for forest and rangeland health, such as resiliency from insect, disease, and drought stress, have also declined (Busby *et al.* 1994; Samson *et al.* 1994).

Across the lower 48 States the diversity of native species populations and habitats have declined and continue to be at risk, primarily in response to human-caused mortality or direct habitat displacement (Flather *et al.* 1994; Marcot *et al.* 1997; Flather *et al.* 1998; Raphael *et al.* 1998; Wisdom *et al.* 2000). Recent post-settlement trends indicate that risk to native species diversity is now primarily a result of declining habitat quality compared with pre-settlement habitats. Stream and watershed conditions declined early in the 20th Century in direct response to damage from human land and water development; however, recent impairments are associated with cumulative effects from increased wildfire severity, road networks, and departure from natural flows of water and nutrient cycles (Rosgen 1994; Lee *et al.* 1997, 1998; Rockwell 1998). Human populations have steadily increased since the early 1900s (Campbell 1994; Haynes and Horne 1997). Demands for use of public lands have shifted from an emphasis on production to an emphasis on recreation.

Despite Federal public land management laws (e.g. Clean Air Act, Clean Water Act, Endangered Species Act, National Forest Management Act, National Environmental Protection Act) and subsequent policies, funding, and programs on resource management and conservation, many conditions continue to be degraded. We (the authors) suggest the lack of positive recovery of many of these conditions can be attributed to a lack of integrated fire and resource planning and implementation linked across multiple scales.

Planning at multiple scales

Land, resource, and fire management plans for National Forest and Grasslands, Bureau of Land Management lands, National Parks and Monuments, National Wildlife Refuges, and other Federal land management agency administrative units, as well as national and regional policies, programs, and funding, have traditionally been tactical, focusing on allocating, funding, and scheduling uses such as timber harvest, livestock grazing, recreation, mining, or oil and gas, and providing protection or mitigation direction for fire, wildlife, aquatic, watershed, and cultural resources. Hierarchical to these plans, site- and time-specific project plans evaluate alternatives and disclose potential effects of some activities, such as prescribed fire, timber harvest, road construction, weed control, or grazing allotment plan revision. In recent decades, broad-scale individual resource or fire planning efforts have emerged as one way to amend one or a group of administrative unit plans and to provide rationale (e.g. when to allow a natural lightning ignition to burn as a wildland fire or when and how to treat an invasion of noxious weeds). However, these efforts do not integrate both resource and fire programs within and across multiple scales.

Three fundamental issues related to this traditional type of planning seem to lead to lack of achievement of multi-scale integrated resource and fire objectives:

1. Differences in scale of ecological processes and key ecosystem components are not addressed. Thus, management or mitigation not designed for the scale of the ecological or socioeconomic process may not be successful or may have unintended consequences on other ecological processes or components;
2. Key ecological processes of change and disturbance (for example succession, wildfire, and timber harvest) are not integrated with their effects on key ecosystem components (for example old forest dependent species, old forests, and timber to mills); therefore, managers are often unable to articulate the full range of risks that may follow from traditional independent management practices, and consequently may not design projects aligned with the operation of natural ecological processes and maintenance of key ecosystem components; and
3. The traditional approach relies on the local administrative unit to understand temporal and spatial changes in conditions and does not provide a system to monitor or summarize changes across larger areas. Therefore, local managers are often unable to articulate the range of cumulative effects and regional and national managers are often unaware of the consequences or benefits of these effects.

In recent years, following the adoption by most Federal public land management agencies of ecosystem management, multi-scale integrated planning has been identified as a way to link broad-scale plans with administrative unit and site-specific project plans in a connected hierarchy that maximizes efficiency at each scale. That is, multi-scale integrated planning provides contextual and multi-disciplinary information that aids in prioritizing and scheduling activities and investments. Within such context, the design and execution of integrated projects can be more successful at achieving objectives not only at the

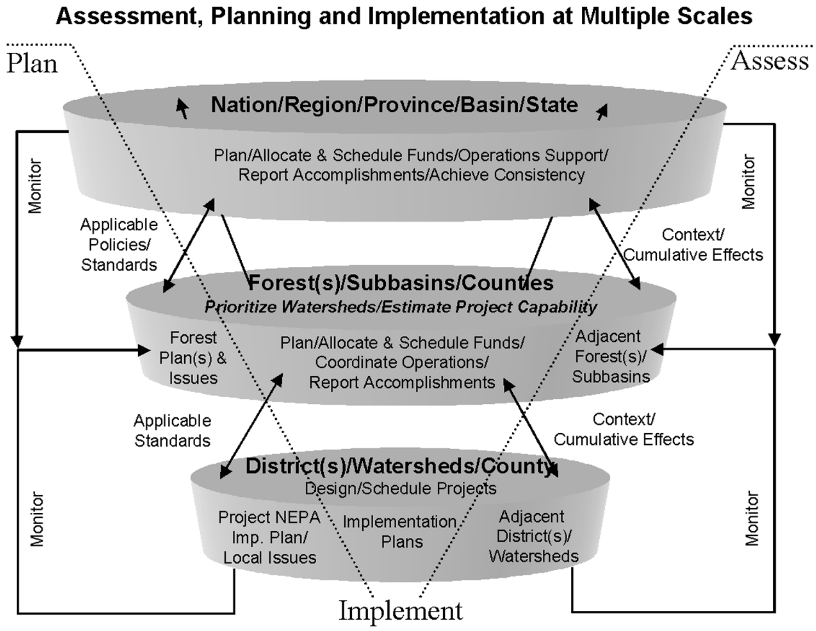

Fig. 1. Multi-scale linkages between planning and assessment levels. At any level, planning and assessment issues tie to administrative boundaries, or natural or human system boundaries. Planning at the level of the Nation and Region provides policies or coarse-scale decisions on standards that apply to finer planning levels. Assessment at this scale provides a summary of conditions, trends, and processes that affect finer scale relationships and support coarse-scale planning. At the Forest level, the focus is on identifying and prioritizing projects, and estimating project accomplishments for feedback to the regional and national levels. The focus of the District is on design and scheduling of projects to accomplish the coarser scale priorities.

project level, but cumulatively at regional and national levels.

Wildland Fire Use Plan for the Bob Marshall Wilderness Complex

An example of successful implementation of a plan that considered scale of ecological processes for a set of related fire and vegetation management issues is the Wildland Fire Use Plan for the Bob Marshall Wilderness Complex, an area of about 1 million ha in northwestern Montana just south of Glacier National Park. Fire policy from the 1930s through the early 1980s maintained a net of 2400 ha per year of the fire and vegetation mosaic via wildfires. In comparison, 15–25 000 ha are estimated to have burned per year (authors' unpublished data; not referenced) in the absence of fire suppression. The severe 1988 fire season (Canyon Creek, Gates Park, Red Bench, and Yellowstone fires, among others) resulted, not only from several years of successive and severe drought, but also from more than 50 years of fire exclusion and resultant changes in succession, such as fuel accumulation and the homogenization of large fuel bodies, and changes in disturbance regimes. A new understanding of severe-fire-year fire behavior emerged from this experience and highlighted a need to understand the appropriate scale of potential wildland fire spread in drought years, and its effects on other ecological processes or components. The Bob Marshall Wilderness fire plan was revised in 1989 to reflect this new understanding of fire risk, fire behavior, drought, and changes in vegetation, fuels, and fire regimes based on comparison of current conditions with the historical forest reserve inventory (Ayres 1900, 1901). The new plan substantially increased the understanding of how to manage wildland fires to address this newfound understanding of the issue of scale.

The Bob Marshall Wilderness fire plan provides an example of a key transition between traditional planning and planning focused on the scale of the ecological processes (issue 1, above). However, to be successful on a wide array of issues, integrated multi-scale planning should address not only the changes in key components at each scale, but also interwoven effects on ecological and socioeconomic processes and components across multiple scales (issue 2, above). In addition, it should provide interactive feedback of this understanding to help guide policy and program direction, funding, and implementation (issue 3, above). In Fig. 1, we conceptually illustrate this process for national forests and national grasslands.

The Upper Arkansas Assessment

The Upper Arkansas Assessment (McNicoll *et al.* 1999) provides an example of administrative unit assessment and planning that, absent a regional or national plan, develops context at the ecological province and hydrologic basin level to prioritize landscape restoration and aid in project design. The Upper Arkansas assessment area is located in central Colorado and encompasses about 300 000 ha of land administered by the Forest Service and Bureau of Land Management. The existing Forest and Resource Plans did not address many developing issues in the area. For the assessment, McNicoll *et al.* (1999) quantified 44 watersheds within the Upper Arkansas assessment area with available data, or rated them using local expert opinion into high, moderate, and low risk and opportunity for sub-issues and summary issues based on current status, investment needed, possibilities of return on investments, and collaborative interest for various types of management projects, restoration activities, and conflict resolution. Hierarchical to this assessment, they designed and implemented an 8000-acre landscape restoration project in the Box Creek watershed, which the assessment had identified as a high priority watershed. This project successfully addressed a complex set of local and coarser-scale integrated objectives including decline in landscape health, wildland fire risk, dwarf mistletoe, lynx habitat restoration, high levels of dispersed recreation use, commercial timber and land exchange expectations, high density road networks, and expectations for increased big game winter range.

Interior Columbia Basin Ecosystem Management Project (ICBEMP)

Full recognition of the complexity of multi-scale integrated planning came to the forefront with development of the Interior Columbia Basin Ecosystem Management Project (ICBEMP), which addressed a variety of highly complex issues, such as migratory fish, terrestrial species endangerment, forest and rangeland health decline, timber production, and noxious weeds. The ICBEMP conducted an assessment and developed a plan for management of 53 million ha of Forest Service and BLM lands in the states of Oregon, Washington, Idaho, and Montana (Quigley *et al.* 1996; Quigley and Arbelbide 1997; USDA and USDI 2000*a*; Haynes *et al.*, in press). Approximately 25% of the National Forests and Grasslands and 10% of Bureau of Land Management lands are within this area. The ICBEMP assessment used a variety of data on changes in fire regimes, vegetation, roads, hydrology, aquatic species, terrestrial species and habitats, and many other attributes to summarize historical to current and future scenarios of trends for ecosystem health and integrity, landscape disturbance regimes, terrestrial and aquatic species and habitats, and socioeconomic conditions. It summarized risks to these systems and opportunities for restoration to subbasins that ranged from about half to 1 million ha in size. These risks and opportunities were then used to formulate alternatives for restoration of ecosystems, as well as protection of key aquatic and terrestrial habitats. Key to the formulation of these alternatives was the development of *step-down* planning procedures that provide management units with guidance and requirements for integration within and between scales and recognition of landscape limits. In *step-down* planning, the success of fine-scale projects also serves to validate and further refine the larger scale contextual information.

Analysing the ICBEMP process, Quigley *et al.* (1996, 1998), Haynes and Quigley (in press), Hann *et al.* (1998), and Hann *et al.* (in press) found that active restoration and protection activities designed in an integrated multi-scale and multi-disciplinary context resulted in more positive outcomes than similar activities designed through traditional single-scale or component planning methods. Traditional methods were found to be embodied in the current Forest and Resource Plans or affected by various protection standards for threatened and endangered species. Minimizing the cost per area of information for coarse- and mid-scale assessment and planning by using the coarsest scale of data, and estimates from experts, to produce summary information of adequate accuracy to make relative decisions among areas of priority, alternative investment levels, or effects of levels of protection appears to be an additional key to efficient multi-scale integrated planning. Hann *et al.* (in press) demonstrated this efficiency for the ICBEMP.

A national example

What are the implications of multi-scale integrated planning compared with traditional planning in the development of general budget and restoration strategies for fire and land management at a national scale, and the step-down of these strategies to administrative unit and project scales? To better understand this question and to provide an example, we developed a landscape dynamics model that linked these issues across the National Forests and Grasslands in the 48 conterminous United States. We selected the National Forests and Grasslands as an example because they represent a wide range of ecosystems across the lower 48 States and account for a substantial component of Federally administered public lands.

An example national landscape dynamics model

We developed an example national landscape dynamics model using the vegetation dynamics development tool (Beukema and Kurz 1999); a computer model that allows the user to assign components with rates of change to another component, in response to ecological processes (see Fig. 2). Egler (1954) first developed concepts for this type of model of ecological components and processes. These concepts

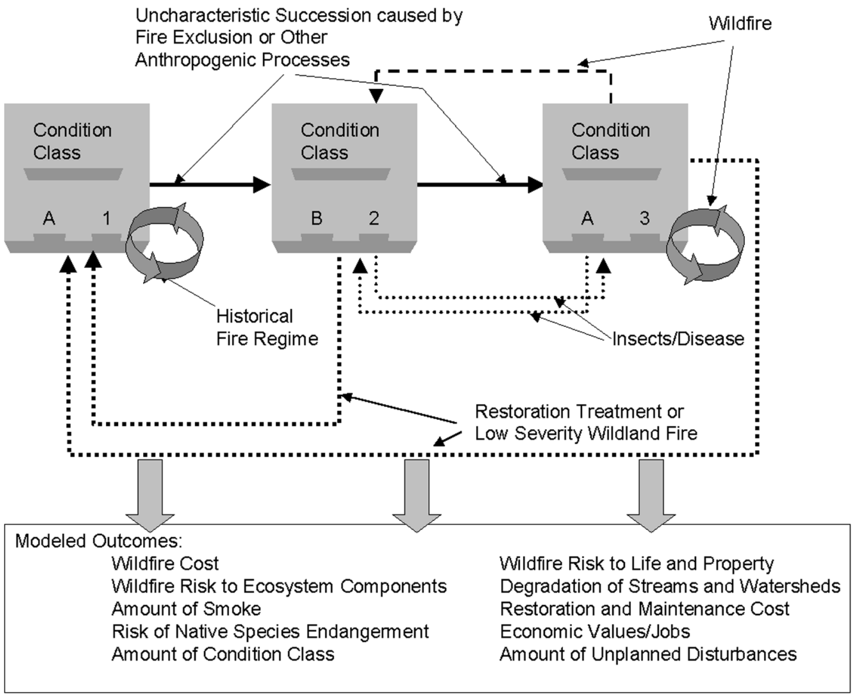

Fig. 2. A simplified diagram of the example landscape dynamics model for National Forests and Grasslands of the lower 48 States. The predicted 'states' of the model are condition classes following the definitions of Hardy et al. (2001). The dynamic processes that change the condition class include both unplanned and planned disturbances. From this basic model other outcomes, such as those shown, can be predicted.

were later incorporated into the developments of conceptual models by Noble and Slatyer (1977). Conceptual models were combined with ecosystem specific information into computer models by Kessell and Fischer (1981) and Keane (1987) to predict response over time of many interactions. These models were further enhanced (Keane *et al.* 1989, 1996, 1999) as concepts of spatial and temporal patterns and processes developed in the field of landscape ecology (Forman and Godrun 1986; Turner *et al.* 1989; Turner and Romme 1994; Forman 1995). State and transition model concepts were further expanded with findings on multiple pathways and steady states in rangelands by Tausch *et al.* (1993).

The ICBEMP and other regional efforts have used cover types and structural stages as conditions for modeling landscape dynamics (Keane *et al.* 1996, Hann *et al.* 1997*a*). However, for the example landscape dynamics model at a national scale, these kinds of vegetation classifications are too complex for general scenario comparisons. Therefore, our model used *condition classes* stratified by *fire regime* as the core response units and incorporated relative probabilities for succession, unplanned disturbances (such as fire), planned disturbances (such as mechanical and prescribed fire restoration), and other anthropogenic effects (such as roads). The model was developed to reflect the average conditions and dynamics of the lower 48 States.

Condition classes (Table 1) and fire regimes (Table 2), developed by Hardy *et al.* (2001), simplify the complexity of the multiple combinations of vegetation cover types, densities, fuel types, successional pathways, and site potentials. Using these condition classes, Hardy *et al.* (2001) estimate that the current average for the lower 48 States on Forest Service lands is about 30% in condition class 1, 40% in condition class 2, and 20% in condition class 3. The condition classes are similar to the 'composite historical range of variability departure' variable described by Hemstrom *et al.* (in press) for the ICBEMP, such that condition class 1 would have low or no departure from the historical or natural range of variability, while condition classes 2 and 3 would have moderate and high departure, respectively. In addition to using the amounts of different condition classes and the information on fire regime dynamics from Hardy *et al.* (2001) to develop the model pathways and change probabilities, we adjusted pathways and probabilities based on a wide range of applicable literature (Kuchler 1964; Keane *et al.* 1990, 1996; Delcourt and Delcourt 1991; Brown and Bradshaw 1994; Brown *et al.* 1994; Covington *et al.* 1994; Morgan *et al.* 1994; Mutch 1994; Swanson *et al.* 1994; Huff *et al.* 1995; McKenzie *et al.* 1996; Hann *et al.* 1997*a*, 1997*b*, 1998; Reinhardt 1997; Saab and Rich 1997; Agee 1998; Frost 1998; Lee *et al.* 1998; Leenhouts 1998; Raphael *et al.* 1998; Rockwell 1998;

Table 1. Condition classes from Hardy *et al.* (2001) as interpreted by the authors for modeling landscape dynamics and departure from historical (natural) range of variability for National Forests and Grasslands in the lower 48 States

Historical Range of Variability (HRV)–the variability of regional or landscape composition, structure, and disturbances, during a period of time of several cycles of the common disturbance intervals, and similar environmental gradients, referring, for the United States, to a period prior to extensive agricultural or industrial development. It is not synonymous with the historical scenario (Hann *et al.* 1997*a*, after Morgan *et al.* 1994). Natural Range of Variability (NRV)–the ecological conditions and processes within a specified area, period of time, and climate, and the variation in these conditions, that would occur without substantial influence from human mechanisms (synthesized from Morgan *et al.* 1994; Swanson *et al.* 1994; Hann *et al.* 1997*a*; Landres *et al.* 1999, Swetnam *et al.* 1999)

Condition class	Departure from HRV or NRV	Description
Class 1	None, minimal, low	Vegetation composition, structure, and fuels are similar to those of the historic regime and do not pre-dispose the system to risk of loss of key ecosystem components. Wildland fires are characteristic of the historical fire regime behavior, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are within the historical range of variability. Smoke production potential is low in volume
Class 2	Moderate	Vegetation composition, structure, and fuels have moderate departure from the historic regime and predispose the system to risk of loss of key ecosystem components. Wildland fires are moderately uncharacteristic compared to the historical fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are outside the historical range of variability. Smoke production potential has increased moderately in volume and duration
Class 3	High	Vegetation composition, structure, and fuels have high departure from the historic regime and predispose the system to high risk of loss of key ecosystem components. Wildland fires are highly uncharacteristic compared to the historical fire regime behaviors, severity, and patterns. Disturbance agents, native species habitats, and hydrologic functions are substantially outside the historical range of variability. Smoke production potential has increased with risks of high volume production of long duration

Table 2. Natural (historical) fire regime classes from Hardy *et al.* (2001) as interpreted by the authors for modeling landscape dynamics for National Forests and Grasslands in the lower 48 States

Fire regime class	Frequency (Fire return interval)	Severity	Modeling assumptions
I	Frequent (0–35 years)	Low	Open forest or savannah structures maintained by frequent fire; also includes frequent mixed severity fires that create a mosaic of different age post-fire open forest, early to mid-seral forest structural stages, and shrub or herb dominated patches (generally < 40 ha (100 acres)).
II	Frequent (0–35 years)	Stand replacement	Shrub or grasslands maintained or cycled by frequent fire; fires kill non-sprouting shrubs such as sagebrush which typically regenerate and become dominant within 10–15 years; fires remove tops of sprouting shrubs such as mesquite and chaparral, which typically resprout and dominate within 5 years; fires typically kill most tree regeneration such as juniper, pinyon pine, ponderosa pine, Douglas-fir, or lodgepole pine.
III	Less frequent (35–100 years)	Mixed	Mosaic of different age post-fire open forest, early to mid-seral forest structural stages, and shrub or herb dominated patches (generally < 40 ha (100 acres)) maintained or cycled by infrequent fire.
IV	Less frequent (35–100 years)	Stand replacement	Large patches (generally > 40 ha (100 acres)) of similar age post-fire shrub or herb dominated structures, or early to mid-seral forest cycled by infrequent fire.
V	Infrequent (> 100 years)	Stand replacement	Large patches (generally > 40 ha (100 acres)) of similar age post-fire shrub or herb dominated structures, or early to mid to late seral forest cycled by infrequent fire.

Graham *et al.* 1999; Hessburg *et al.* 1999*a*, 1999*b*, 1999*c*; Sheley and Petroff 1999; Swetnam *et al.* 1999; Wisdom *et al.* 2000).

Management scenarios for a national example model

The 'historical to current' scenario was designed to illustrate the dynamics of system conditions and ecological processes that operated dynamically between historical and current periods. For modeling purposes, the historical conditions were assumed to represent the approximate composition at the year 1900 and the current conditions were assumed to represent the approximate composition at the year 1999. The known conditions in the model were the starting historical composition of fire regime condition classes and the ending current composition. General levels of historical timber harvest were available from the annual

Table 3. Comparison of three management scenarios of National Forest and Grasslands in the lower 48 States

Attribute	Scenario		
	Continuation of Current at 0.7% per year	Increase Current to 2% per year	Integrated at 2% per year
Treatment area	0.7% land area per year	2% land area per year	2% land area per year
Coarse-scale policy or assessment	Distribute funds	Limited/non-prioritized ecosystem objectives	Integrated landscape priorities and outcomes
Mid-scale plan or assessment	Forest or Grassland standards and objectives	Forest or Grassland standards and objectives plus national/regional objectives	Prioritize watersheds for restoration with integrated landscape outcomes
Fine-scale plan	Project plans to achieve local fire or individual resource program objectives within Forest Plan standards	Project plans to achieve multiple local and national/regional fire and resource program objectives	Project plan for landscape mosaic to achieve multi-scale integrated outcomes
Typical project size	10–200 ha	10–200 ha	400–4000 ha
Objective	Single resource or fire program objective	Multiple fire and resource program objectives	Integrated landscape fire and resource objectives

Forest Service reports (USDA FS 1960–1999). Given these known conditions and probabilities, other probabilities were adjusted through the multiple iterations, until the current conditions were achieved at the end of the 100-year simulation.

Three scenarios were identified to simulate future outcomes (see Table 3). These included: (1) *continue current at 0.7% per year*; (2) *increase current to 2% per year*; and (3) *integrated at 2% per year*. The *continue current at 0.7% per year* scenario assumes that the National Forest and Grasslands will continue to be managed from relatively independent functional (fire, forest, range, wildlife, watershed, fish, recreation) programs and scales (national, regional, local, project), and that restoration and maintenance projects will be designed at traditional scales (Table 3) rather than scaled to ecological processes (Tables 3 and 4).

Experience with ICBEMP data (Hann *et al*. 1997*a*, 1997*b*, in press) indicates that to reverse current trajectories of decline in landscape health and departure from natural conditions and processes across large areas requires maintenance and restoration treatments on at least 2% of the land base per year. We ran the uncalibrated *continue current* model for multiple simulations to determine if an increase in restoration and maintenance activities to 2% of the land base per year could attain a positive response in condition class 1 (used as a proxy for landscape health), stabilize or decrease amount of wildfire uncharacteristic to its natural fire regime (used as a proxy for departure from natural processes), and stabilize or achieve a positive response in other attributes. We limited the amount of maintenance and restoration activity to the 2% level because of recognition that the Forest Service could reasonably increase restoration and maintenance activities per year by only three-fold or four-fold before being constrained by shortages of people with appropriate skills or technological limits.

This is not an assumption, but recognition based on our knowledge of reasonable increases that have been achieved over past decades. The maintenance and restoration treatments were assumed to include prescribed fire, wildland fire use, mechanical fuel reduction, hand treatments, timber stand improvement, forest health treatments, range allotment improvement, weed control, watershed restoration, wildlife and fishery habitat restoration, reduction of negative road effects, as well as others designed to achieve integrated restoration objectives at landscape scales. We found that maintenance and restoration of 2% of the National Forests and Grasslands per year was adequate to achieve the desired response. However, we also found that increased levels above 2% could achieve the desired responses faster and to a higher degree, if operations were not limited by technology or the availability of skilled people.

The *increase current to 2% per year* scenario assumes that the National Forests and Grasslands will continue to be managed as in the *continue current* scenario, but with an increase in restoration and maintenance to about 2% of the land base per year. The *integrated at 2% per year* scenario assumes that, from the scale of project design to Forest Plans to national policies and funding, desired outcomes are integrated within the appropriate landscape scale of delineation (see Fig. 1), and based on an understanding of the linkages and scales of key ecological and socioeconomic conditions and processes (Tables 3 and 4). To achieve an equitable comparison of outcomes between the *increase current* and *integrated* scenarios, integrated restoration and maintenance treatments were also assumed to occur on about 2% of the land base per year.

Modeling of the future outcomes for the scenarios *continue current at 0.7% per year* and *increase current to 2% per year* were relatively easy to calibrate. The *continue current* scenario was adjusted to include current types of treatments as discussed earlier to improve forest and

Table 4. Scaling restoration area size, type of treatment, and measure to the scale of the ecological or social risk issue for National Forests and Grasslands in the lower 48 States

Information includes broad ranges of values and interpretations that are not specific to any one type of landscape. Information developed from authors' knowledge and unpublished data pertaining to National Forests and Grasslands in the lower 48 States. HRV, historic range of variability; NRV, natural range of variability: see Table 1

Risk issue	Contiguous size of project to reduce risk	Type of treatment	Assessment and monitoring issues
Landscape Health and Forest-Range sustainability	400–4000 ha	Restore/maintain landscape mosaic to Condition Class 1; restore/stabilize streams, riparian areas, roads, soils	Condition Class; fire regime; HRV departure; NRV departure; landscape health
Wildland urban fire interface	50–100 m from structures; 1–2 km wildfire/firebrands	Structure and infrastructure area safety; thinning small diameter trees; piling/burning/ chipping fuel	Structure and surrounding area safety rating; wildfire risk; fire suppression preparedness
Wildfire size, severity and cost	400–8000 ha	Restore/maintain landscape mosaic to Condition Class 1; Suppression preparedness	Wildfire size, severity, and cost prediction
Firefighter fatality and severe accident	400–8000 ha	Restore/maintain landscape mosaic to Condition Class 1; Suppression preparedness; firefighter training	Fatality and severe accident prediction
Forest insect (bark and pine beetle) vulnerability	400–8000 ha	Restore/maintain landscape mosaic to Condition Class 1	Hazard Index
Forest disease (mistletoe, root disease) vulnerability	40–400 ha	Restore/maintain landscape mosaic to Condition Class 1	Hazard Index
Watershed vulnerability	0.4–40 ha point source; 400–4000 ha watershed	Restore point source; maintain/rehabilitate roads; restore watershed system	Watershed condition; impaired streams; hydrologic indicators
Air-shed vulnerability	400–800 000 ha	Restore/maintain landscape mosaic to Condition Class 1	Smoke, visibility, and particulate predictions
Anadromous species and habitats	400 000–800 000 ha	Protect species population strongholds from disturbance; restore habitat connectivity between strongholds; maintain landscape mosaic to Condition Class 1inside strongholds	Anadromous aquatic strongholds; anadromous species endangerment predictions
Aquatic species and habitat endangerment	400–4000 ha	Protect species population strongholds from disturbance; restore point source; restore landscape mosaic to Condition Class 1 outside strongholds; maintain landscape mosaic in Condition Class 1 inside strongholds	Aquatic strongholds; aquatic species endangerment predictions
Riparian terrestrial species and habitats	0.4–40 ha point source; 400–4000 ha watershed	Maintain quality populations and habitats; restore and maintain riparian habitats	Hydrologic indicators; species habitat/ population model predictions; riparian HRV departure
Forest-shrubland-grassland mosaic terrestrial species and habitats	400–8000 ha	Maintain quality populations and habitats; restore and maintain landscape mosaics of forest–shrubland–grassland	Species habitat/population model predictions; HRV departure
Shrubland–grassland mosaic terrestrial species and habitats	400–8000 ha	Maintain quality populations and habitats; restore and maintain landscape mosaics of shrubland–grassland	Species habitat/population model predictions; HRV departure

rangeland health and reduce fuel hazards at a level affecting about 0.7% of the land area per year. This same model was used for the *increase current* scenario with an increase of land area treated per year to 2%. The *integrated* scenario was more difficult to calibrate. Hann *et al.* (in press) suggest that 'efficiencies of scale' (increased size of projects and integration to achieve multiple positive program outcomes) could both reduce cost per unit area of treatments and increase effectiveness of restoration of landscape scale conditions and processes. However, this work is specific to the environments of the interior Columbia River basin and does not account for the moister and more resilient conditions of the eastern U.S. or coastal west, nor the prairie, desert and dry mountain conditions of the central U.S. and southwest. We used a coefficient of improvement for landscape outcomes derived from the Hann *et al.* (in press) results for the interior Columbia River basin and then ran multiple simulations for other areas of the lower 48 States in

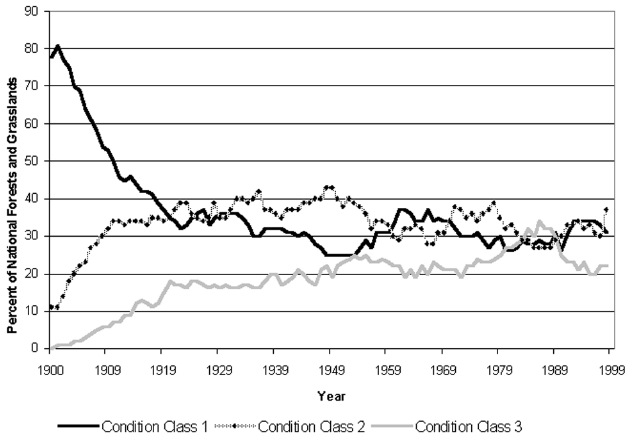

Fig. 3. Amounts of condition classes 1, 2, and 3 (% of land area) predicted to have occurred from 1900 to 1999 for National Forests and Grasslands in the lower 48 States.

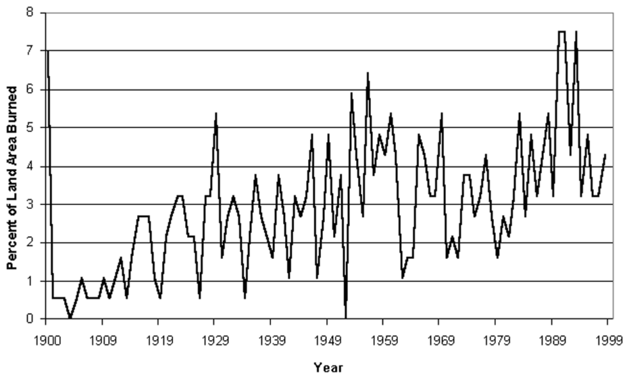

Fig. 4. Amount of wildfire per year (in % of land area burned) predicted to have occurred from 1900 to 1999 for the National Forests and Grasslands in the lower 48 States.

which we adjusted the coefficient to reflect the differing conditions. From these multiple simulations and coefficients we approximated probabilities for the National Forests and Grasslands of the lower 48 States.

Modeling Outcomes for the National Example Model

The basic structure of the landscape dynamics model provides scenario outcomes for the conditions and processes that drive the model (see Fig. 2). These include amounts of condition classes, wildfire and other unplanned disturbances (such as insects or disease), fire exclusion, succession, commodity management, human settlement, effects of roads, and restoration and maintenance (such as prescribed fire or thinning).

In addition, we developed associated attribute models to estimate scenario wildfire cost, restoration and maintenance cost, wildfire risk to life and property, wildfire degradation of key ecosystem components, degradation of streams and watersheds, amount of smoke, risk of native species endangerment, and economic values and jobs. For wildfire and restoration and maintenance cost coefficients we used average costs per unit area reported by Hann *et al.* (in press) for the Interior Columbia Basin with some modification to account for higher and lower costs across the lower 48 States. For wildfire risk to life and property we used a similar approach as Hann *et al.* (in press) to correlate the firefighter fatality and accident data from Mangan (1999) and the National Interagency Fire Center (1997) with extent and severity of wildfires. Wildfire degradation of key ecosystem components (such as loss of large, old trees, the combination of cyclic wildfire and exotic plant invasions, or soil erosion from runoff events on hydrophobic soils) was calculated by modeling scenarios of first order fire effects (Keane *et al.* 1990; Reinhardt 1997). Amount of smoke was modeled using a similar approach.

The coefficient for degradation of streams and watersheds was developed using similar correlation techniques as those used by Lee *et al.* (1997), Hann *et al.* (1997*a*, 1997*b*), and Rieman *et al.* (in press) for the interior Columbia River basin, but adjusted for conditions across the lower 48 States. Risks of native species endangerment were developed through correlation of the historical to current model conditions and processes with the findings of Flather *et al.* (1994, 1998) on species endangerment trends in the United States. In addition, we developed coefficients for an economic index based on estimates of cost of restoration, maintenance, and wildfire rehabilitation; cost of wildfire suppression; and estimates of associated commodity outputs.

Results from an example national landscape dynamics model

Historical to current

Model results indicate a steep drop in condition class 1 for National Forests and Grasslands in the lower 48 States early in the 20th Century, followed by a leveling out of the curve with high fluctuations (Fig. 3). In response condition class 2 increases sharply, levels out, and then decreases slightly as condition class 3 increases. The current condition estimates may have been strongly influenced by the averaging effect of differences among the northeast, southeast, and west on changes in condition classes that occurred on National Forests and Grasslands in the lower 48 States. For the northeast and southeast, condition class 1 dropped steeply in the 19th Century, while in the west a similar drop did not occur until the 20th Century. In addition, considerable restoration of condition classes 2 and 3 to condition class 1 and maintenance of this restoration has occurred in the southeast over the past 30 years, raising the average amount of condition class 1. Consequently, amount of condition class 1 is much lower for the northeast and the west.

Trends in wildfire from 1900 to current indicate a steep drop early in the last century following implementation of suppression and then a steady increase to current levels

Table 5. Summary of average predicted changes in outcomes for National Frests and Grasslands in the lower 48 States from historical to current, and for three future management scenarios compared to current

Current to historical comparison = (current amount–historical amount)/(historical amount) × 100. Current time period is considered to be the average condition for the 1990s. Historical time period is considered to be the succession and disturbance regime that occurred during a similar climate prior to European and American settlement. This time period varies from the eastern to western U.S. Future compared to current = (future amount–current amount)/(current amount) ×100. Landscape, forest, and rangeland health is defined as the 'best fit' of the dynamic interactions of human land use, biodiversity, and ecosystem health that are in balance with the limitations of the biophysical system and inherent disturbance processes (Hann *et al.* 1997*a*)

Outcome variable	Current to historical comparison	Future to current scenario comparison		
		Continue Current at 0.7% per year	Increase Current to 2% per year	Integrated at 2% per year
		Percentage change		
Cost of wildfire suppression	+150	+290	+120	–20
Wildfire risk to life and property	+200	+330	+70	–30
Risk of smoke production and air quality degradation	+220	+160	+80	–25
Risk of declining landscape, forest, and rangeland health	+150	+300	+200	–40
Wildfire degradation of key ecosystem components	+150	+300	+240	–40
Risk of native species endangerment	+500	+270	+330	–10
Degradation of streams and watersheds	+280	+180	+230	–20
Cost of maintenance, restoration, and wildfire rehab.	+500 (to 1970s) –20 (1970s to 2000)	+550	+850	+770
Economic index US dollar value	+300 (to 1970s) –30 (1970s to 2000)	+100	+400	+300

(Fig. 4). Though the levels vary year by year, the general trend in wildfire area burned and associated costs and damage is increasing. Agee (1993) reports similar findings of recorded wildfire trends in the west, although his results differ in specific wildfire amounts and timing. This difference occurs because our model is based on predicted values versus recorded values, and also because of the averaging between the east and the west of the time period of implementation of effective fire suppression. In addition, recent national wildfire trends are different because of changes on National Forests and Grasslands in the southeast. Data from the southeast indicate a reduction in wildfire area burned and associated suppression cost and damage, during the past decade, in areas where condition classes 2 and 3 have been restored to condition class 1 (Ferguson 1998).

In association with increases in wildfire to near historical levels the costs of wildfire suppression, wildfire risks to life and property, and amount of smoke have also increased (Table 5). In association with the declines in condition class 1 related to historical management activities and fire exclusion, as well as linked effects of adjacent settlement and road network development, landscape health, wildfire degradation of key ecosystem components, native species endangerment, and degradation of streams and watersheds have increased (Table 5). In contrast, our economic index dollar value indicated a decrease of jobs associated with communities dependent on economic values from National Forests and Grasslands in the latter 1900s.

Future trend of scenarios

For the *continue current at 0.7% per year* scenario, condition class 1 declined from about 30% to about 25% of total National Forest and Grasslands in the lower 48 States. Given that the southeast is maintaining most of their condition class 1, this decline is occurring mostly in the west and northeast. In contrast, the *integrated at 2% per year* scenario produced an increase in condition class 1 to approximately 50% of the land area, while the *increase current to 2% per year* resulted in a slight increase to about 35% (Fig. 5).

For the *continue current at 0.7% per year* scenario, condition class 2 increases to about 40% of the land area and then declines steadily to about 25% at the end of the 100-year simulation. In comparison, the *integrated at 2% per year* scenario produced a much more rapid decrease in condition class 2 to the 25% level in about 30 years. With an apparent intermediate outcome, the *increase current to 2% per year* scenario produces a steep decrease in about 30 years, but to only about 30% (Fig. 6).

For the *continue current at 0.7% per year* scenario, condition class 3 increases quite steeply to about 45% of the land area. In comparison, the *integrated at 2% per year*

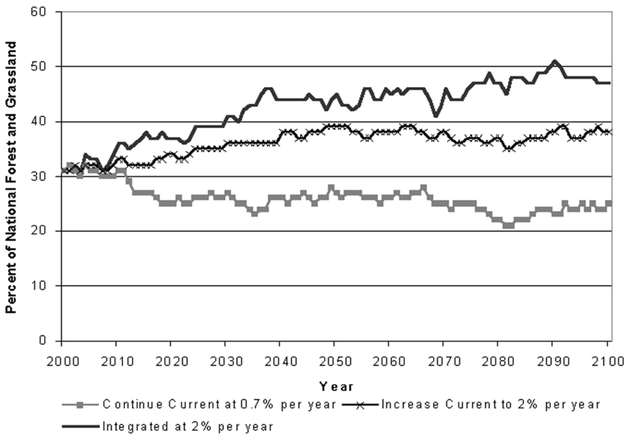

Fig. 5. Amount of condition class 1 in % of land area predicted for three different management scenarios on National Forests and Grasslands in the lower 48 States from 2000 through 2100.

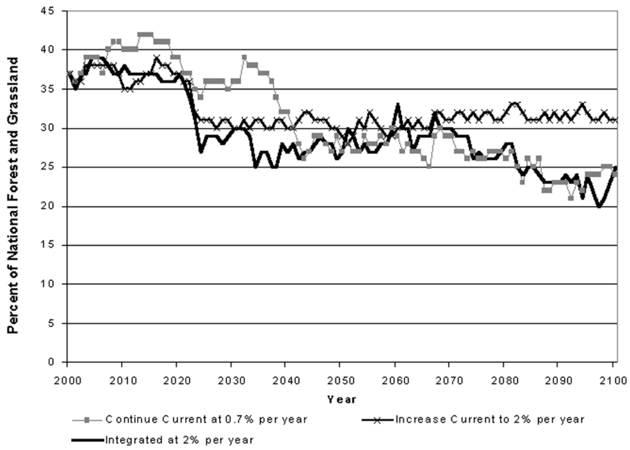

Fig. 6. Amount of condition class 2 in % of land area predicted for three different management scenarios on National Forests and Grasslands in the lower 48 States from 2000 through 2100.

scenario produces a slight decline to a level of about 20%. The *increase current to 2% per year* scenario fluctuates around the current level (Fig. 7).

In correlation with these changes the amount of wildfire *for the continue current at 0.7% per year* scenario steadily increases until about the middle of the 100-year simulation and then levels off at about 13% of the land area, with high years ranging up to 18% (Fig. 8). In contrast, the *integrated at 2% per year* scenario curbs the increases and produces a decline to approximately 5%, while the *increase current to 2% per year* results in slightly lower average amounts than the *continue current at 0.7% per year* scenario. This lack of response of the *increase current to 2% per year* scenario for a three-fold increase in restoration and maintenance is primarily correlated with the lack of scaling of treatment size to the ecological process scale of wildfire (Table 3). Although the amount of condition class 1 substantially increases, associated influence on wildfire size, behavior, and severity because of small and scattered patch size is low.

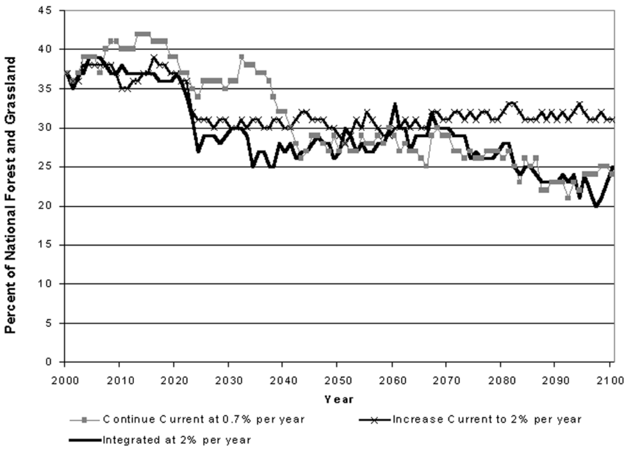

Fig. 7. Amount of condition class 3 in % of land area predicted for three different management scenarios on National Forests and Grasslands in the lower 48 States from 2000 through 2100.

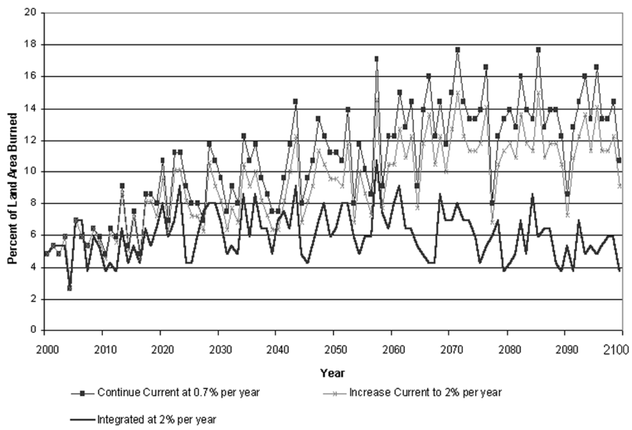

Fig. 8. Amount of wildfire per year (% of land area) predicted to occur from 2000 to 2100 for three different management scenarios for the National Forests and Grasslands in the lower 48 States.

In association with increase of wildfire (to well above historical levels) and declines or no substantial improvement in condition class 1 (for the *continue current at 0.7% per year* and *increase current to 2% per year* scenarios, respectively), costs of wildfire suppression, wildfire risks to life and property, amount of smoke, landscape health, and wildfire degradation of key ecosystem components increase for the *continue current at 0.7% per year* and *increase current to 2% per year* scenarios (Table 5). In contrast the risk of native species endangerment and degradation of streams and watersheds also increase, but with higher risk for the *continue current at 0.7% per year* scenario (Table 5). This higher risk for the *increase current to 2% per year* scenario is related to the cumulative effects of the three-fold increase in restoration and maintenance activities without *integrated* scaling to the ecological processes of native species, integration of treatment design, and prioritization of integrated areas for restoration versus short-term protection from activity disturbance of strong, but disjunct native populations (Tables 3 and 4; Fig. 1).

Economic index dollar value associated with communities dependent on economic values from National Forests and Grasslands increases four-fold for the *increase current to 2% per year* scenario and three-fold for the *integrated at 2% per year* scenario (Table 5). However, although both these scenarios contain similar amounts of commodity production, the larger increase in *increase current to 2% per year* scenario is attributable to higher costs for maintenance and restoration and higher costs of wildfire suppression. The *integrated at 2% per year* scenario more efficiently scales restoration investments, thereby reducing costs. Both the *increase current to 2% per year* scenario and *integrated at 2% per year* scenarios increase investment and associated secondary commodity outputs, but the *increase current to 2% per year* scenario produces a higher cumulative value because of higher costs for wildfire suppression, wildfire rehabilitation, and per unit area costs of maintenance and restoration treatments.

Conclusions

Results from these simulations of the *integrated at 2% per year* scenario option indicate that substantial increases in condition class 1 can be achieved with associated decreases in condition classes 2 and 3. This would be paralleled with reduced suppression cost, reduced risk to lives and property, reduced smoke, and reduced wildfire degradation of key ecosystem components. Also in parallel would be substantial improvement in landscape health, native species habitats, stream and watershed conditions, and dollars to local economies. In contrast, the *increase current to 2% per year* scenario only produces a moderate increase in condition class 1 and reduction in condition class 2 with corresponding minimal changes in landscape health and other associated attributes, while the *continue current at 0.7% per year* scenario results in steep declines in condition class 1 and increase in condition class 3. Considerable variation in these trends would occur within the west and between the west, northeast, and southeast, but we (the authors) feel these trends are representative of average outcomes for the National Forests and Grasslands in the lower 48 States.

Based on the example, nationally, for Forest Service lands, we estimate that implementation of integrated maintenance and restoration on about 1.5–2.0 million ha (3.7–4.9 million acres) per year would represent the *integrated* scenario. This level of integrated, multi-scale maintenance and restoration would provide sufficient increase in condition class 1, reduction of condition classes 2 and 3, and restoration of associated ecosystem processes to stabilize and then decrease the amount of uncharacteristic wildfire and associated impacts on ecosystems, smoke, and cost. This level of integrated restoration would also reduce risks to native species, watersheds, air, and landscape health. Implementation of multi-scale integrated planning would be required in order to achieve these multiple objectives that operate at different scales. We estimate the cost to be about 750–850 million US dollars per year, which may result in substantial increase of jobs. The integrated restoration scenario and these cost estimates correlate well with the Federal Fire Policy (USDA and USDI 1995) and the recently approved National Fire Plan (USDA and USDI 2000*b*) and Forest Service Cohesive Strategy (USDA FS 2000).

This example national analysis of conditions and management scenarios on the National Forests and Grasslands of the lower 48 States provides an indication of what could be accomplished on all Federal public lands with an interagency approach to a multi-scale *integrated* scenario. Further analysis would be required to gain an understanding of the variation in landscape dynamics and scenario options for Federal lands by agency and for all Federal lands as a whole.

Public land management agencies could benefit considerably by implementing multi-scale integrated planning and addressing the three fundamental issues that appear to stymy achievement of multiple land and fire management objectives. Under this approach managers would focus on designing policies, plans, and treatments that are scaled to the ecological or socioeconomic process, thereby assuring success and awareness of linked effects to other processes or components. Managers would be aware of the key ecological processes of change and disturbance, and integrate their effects on key components in order to understand the full range of risks. Managers at different levels of land management would interact to understand and monitor temporal and spatial changes in conditions, which would allow them, locally, to locally articulate the range of cumulative effects, and regionally and nationally, to explain the consequences or benefits of these effects.

Much of the scientific literature and many natural resource societies support *ecosystem management* as a potential resolution for many land and fire management issues (Allen and Hoekstra 1992; Christensen *et al.* 1996; Grumbine 1997). Multi-scale, integrated planning based on the principles of landscape ecology provides an avenue for successful implementation of ecosystem management (Haynes *et al.* 1996, and in press; Rieman *et al.* 2000). For substantial change to occur within the management agencies and with regards to congressional funding and law, publication of scientific research that demonstrates applications of integrated multi-scale planning must occur. In addition, education and implementation of integrated multi-scale planning must follow parallel paths within natural resource agencies and in university natural resource programs. These parallel efforts must also be collaborative and adaptive. Large increases in restoration projects should be based not only on conceptual scientific recommendations, but also on specific research in order to survive the rigor of internal and external scrutiny and achieve objectives. Teaching tested restoration techniques in universities will also assure that on-the-ground personnel, those that conduct the planning, design, and implementation, will keep pace with the advances in research and applied restoration techniques.

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